Journal of the Saudi Society of Agricultural Sciences (2013) 12, 109–115

King Saud University
Journal of the Saudi Society of Agricultural Sciences
www.ksu.edu.sa
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FULL LENGTH ARTICLE

Effect of gamma irradiation on the physicochemical and morphological properties of starch extracted from lotus stem harvested from Dal lake of Jammu and Kashmir, India

Adil Gani, Tahir Gazanfar, Romee Jan, S.M. Wani, F.A. Masoodi *

Department of Food Science and Technology, University of Kashmir, Sgr, India

Received 8 May 2012; accepted 27 August 2012
Available online 1 September 2012

KEYWORDS
Lotus stem starch;
Gamma-irradiation;
Physicochemical properties;
Pasting properties;
Morphological properties

Abstract Starch isolated from lotus stem was treated by gamma-irradiation at different doses of 5, 10 and 20 kGy. Physicochemical, morphological and pasting properties of irradiated lotus stem starches were investigated and these properties differed significantly. Carboxyl content, water absorption capacity, amylose leaching, and transmittance increased, whereas swelling power, apparent amylose content, syneresis, and pasting properties decreased after the modification in a dose dependent manner. Observation under scanning electron microscope (SEM) showed that some of the starch granules were destroyed by gamma-irradiation and the breakage was much greater at a higher dose (20 kGy). X-ray diffraction pattern remained the same upon irradiation but a dose dependent decrease in relative crystallinity was observed.

1. Introduction

Lotus (*Nelumbo nucifera*. L) is an edible aquatic perennial herb with nutraceutical value belonging to the monogeneric family Nelumbonaceae widely grown throughout the world. Lotus stem contains ash (1.10%), total nitrogen (1.36%), total protein (8.48%), total sugar (19.08%) and free amino acids (0.78%). The lotus rhizome was found to be a poor source of crude oil (2.68%) (Shad et al., 2011). In India lotus plant reportedly grows in almost all lakes and other water bodies, both at high (1400 m Kashmir, Himalayas, North India), and low altitudes (Kaniya Kumari, Southern India). But the lotus from the Kashmir valley is of prime importance owing to its geographic location and the altitude at which it grows. Starch affects texture, viscosity, gel formation, adhesion, binding, moisture retention, film formation and product homogeneity. It is used mainly in soups, sauces, gravies, bakery products, dairy confectionary, snacks, batters, coatings and meat products (Davies, 1995). Non-food applications of starch include the field of pharmaceuticals, textiles, alcohol-based fuels and adhesives. Native starch is a good texture stabilizer and regulator in food systems (Cousidine, 1982), but limitations such as low shear resistance, low thermal resistance, thermal decomposition and high retrogradation tendency, are not optimal in some

* Corresponding author.
E-mail address: masoodo_fa@yahoomail.com (F.A. Masoodi).
Peer review under responsibility of King Saud University.

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http://dx.doi.org/10.1016/j.jssas.2012.08.004

industrial food applications (Thomas and Atwell, 1999). Starch modification, which involves the alteration of the physical and chemical characteristics of the native starch to improve its functional characteristics, can be used to tailor starch to specific food applications (Hermansson and Svegmark, 1996). Chemical modification is widely implemented, but there is also a growing interest in the physical modification of starch, especially in food applications. The physical modification of starch by radiation has been gaining wider acceptance because no by-products of chemical reagents are present in the modified starch. A major advantage of physical modification is that starch is considered to be a natural material and a highly safe ingredient, so its presence and quantity in food is not limited by legislation (Bemiller, 1997). The irradiation of food products is a physical treatment involving direct exposure to electron or electromagnetic rays for their long-time preservation as well as for the improvement of safety and quality (Urbain, 1986). Irradiation treatments do not induce a significant increase in temperature, require minimal sample preparation, are fast and have no dependence on any type of catalysts (Farkas, 1998; Diehl, 2002). The application of ionising radiation (gamma and electron beam) is reported to generate free radicals that are capable of inducing molecular changes and fragmentation of starch (Ciesla et al., 1991; Grant and D'Appolonia, 1991). This unique property has been suggested to be one of the main mechanisms underlying physicochemical changes in starchy food, like reduction of viscosity and high water solubility (Bao and Corke, 2002; Lee et al., 2003). Apart from food industries, high doses of gamma irradiated starch are also used in paper and textile industries (Roushdi et al., 1983). During radiation treatments (as with gamma rays), the glycoside bonds (at chain endings) are broken down into starch granules, which are later accompanied by the decomposition of macromolecules and the creation of macromolecules with smaller chains (Hayashi and Aoki, 1985). Studies have also shown that there is a decrease in the crystalline phase content as well as in the distribution order of amylose and amylopectin in starch granules (Ciesla et al., 1992). Lotus stem has altogether different growing conditions than cereal and tuber crops which are considered as the main sources of starch for food applications. Sufficient work has been reported for irradiation of cereal and tuber starches, there is a dearth of information regarding irradiation of starches from aquatic sources. Present work was undertaken to study the effect of gamma-irradiation on the physicochemical and morphological properties of lotus stem starch to broaden its food use.

2. Material and methods

2.1. Materials

Lotus stems (*N. nucifera*) were harvested in the month of November from Dal lake Srinagar, Jammu and Kashmir, India.

2.2. Starch extraction

Wet extraction method used by Kaur et al. (2010) was used. The lotus stems were washed, peeled, cut into small pieces and ground in a blender to form a paste. The resultant slurry was sieved through 100 mesh linen cloth into a beaker. Starch suspension was left overnight and extracted by washing with distilled water four times. The resultant slurry was centrifuged at 3200*g* for 10 min. The isolated starch was dried in an air oven at 40^0C for 24 h.

2.3. Gamma-irradiation

Irradiation was done at Baba Atomic Research Centre, Srinagar using Panoramic Batch Irradiator. The starch samples (12% moisture content) were packed in a polyethylene bag and irradiated using ^{60}Co gamma source at ambient temperature (20 ± 0.5 °C).The doses were controlled at 0 (control), 5, 10, and 20 kGy with a dose rate of 2 kGy/h. The irradiation treatments were performed at Baba Atomic Research Centre Zakura, Srinagar, J&K, India.

2.4. Moisture content and apparent amylose content

Moisture was estimated using moisture analyser (Model MA 100, Sartorius Germany).

Apparent amylose contents of the starch samples were determined by the method of Williams et al., 1970. A starch sample of (20 mg) was taken, 10 ml of 0.5 M KOH was added and the suspension was mixed thoroughly. The dispersed sample was transferred to a 100 ml volumetric flask and the volume was made up to the mark with distilled water. An aliquot of the test starch solution (10 ml) was pipetted into a 50 ml volumetric flask and 5 ml of 0.1 M aq. HCl was added followed by 0.5 ml of iodine reagent. The volume was diluted to 50 ml and the absorbance was measured at 625 nm (UV–visible Spectrophotometer, Model U-2900 2JI-0003, Hitachi, Japan). The content of amylose was determined from a standard curve developed using standard amylose and amylopectin blends from potato starch.

2.5. Carboxyl content and pH

The carboxyl content was determined as per the procedure of Mattison and Legendre (1952). To 0.5–1.0 g of starch, 25 ml 0.1 N HCI was added and the mixture was allowed to stand for 30 min with occasional stirring. The slurry was filtered through a fritted glass crucible and washed with distilled water until it was free from chlorine. The starch was then transferred to a 500 ml beaker to which 300 ml distilled water was added. It was then boiled for 5–10 min for complete gelatinisation, followed by titration with 0.1 N NaOH solution with phenolphthalein as indicator. A blank test was also performed with unmodified starch. Carboxyl content was calculated as follows:

$$\text{milli} - \text{Eq.of acidity}/100\text{g starch} = (\text{A} - \text{B}) \times \text{N} \times 100/\text{W}$$

where

A = Titre value for sample
B = Titre value for blank
N = Normality of NaOH
W = Weight of dry sample in grams

$$\text{Apparent \% carboxyl} = \text{milli} - \text{equivalents of acidity} \\ /100\text{g starch} \times 0.045.$$

The pH of starch slurry (40% w/v) was determined using a digital pH metre calibrated at 25 °C.

2.6. Amylose leaching and swelling power

The amylose leaching of starch at 60 °C was measured according to the procedure of Chung et al., 2008. Swelling power of the starch samples were determined by using the modified method of Subramanian et al. (1994). Starch (0.6 g) was mixed with 30 mL of distilled water and stirred at 90 °C on a magnetic stirrer. After 30 min stirring, the mixture was centrifuged at 1500 × g for 30 min. The supernatant was carefully removed, and the swollen starch sediment was weighed (M_1). Swelling power was calculated from the equation given below.

$$\text{Swelling power(g/g)} = M_1/M_0$$

2.7. Water absorption capacity

Water absorption capacity (WAC) of the starches was determined as described by Mishra and Rai, 2006 in triplicate using 2.5% starch suspensions at a temperature of 25 °C. Dried starch samples (0.125 g) were weighed into pre-weighed centrifuge tubes and 5 mL of distilled water was added. The samples were heated at the above temperature for 1 h with constant shaking and thereafter centrifuged for 15 min at 1500 × g. The free water was decanted and the tubes allowed to drain for 10 min at a 45° angle. Subsequently the sample tubes were weighed, and the gain in weight was used to calculate the water absorption capacity.

2.8. Syneresis

Syneresis was determined in triplicate using 5% aqueous starch solution made by adding 5 ml of distilled water to 0.25 g (db) starch in a screw capped centrifuge. The suspension was heated in a boiling water bath for 30 min with constant stirring and then cooled to room temperature in an ice bath. After cooling, the starch pastes were reweighed to determine the amount of starch paste and then placed in a freezer at −20 °C for 48 h. After the freezing period, the samples were placed in 40 °C water for 1.5 h to thaw and equilibrate. Syneresis was measured in triplicate as% water released after centrifuging at 1500 × g for 30 min (Singh et al., 2004).

$$\%\text{Syneresis} = (\text{Wt.of water released}/\text{Wt.of gel}) \times 100$$

2.9. Pasting Properties

Pasting properties were determined using a rapid visco-analyser (RVA Starch Master TM, Newport Scientific, Warriewood, Australia). The test profile STD1 (Newport Scientific Method 1, Version 5, 1997) was used for the determination of pasting characteristics. The sample (3.0 g of starch) was dispersed in water (25.0 ml) and stirred in an RVA container initially at 960 rpm for 10 s and finally at 160 rpm for the remaining test. The temperature profile was started from 50 °C for 1 min followed by ramping the temperature linearly to 95 °C in 3 min and 42 s, holding for 2 min and 30 s, cooling the system to 50 °C in 3 min and 48 s and ending the process in 13 min. The pasting curves obtained were analysed using an RVA Starch Master Software setup Tool (SMST) to obtain the characteristic parameters like peak viscosity (PV), final viscosity (FV) at 50 °C); breakdown (BD = PV-HPV), set back (SB = CPV-HPV).

2.10. Scanning electron Microscopy

The starch granules were placed on an adhesive tape attached to a circular aluminium specimen stub and coated with gold–palladium. The samples were photographed at an accelerator potential of 10 kV using a scanning electron microscope (JSM-6100; JEOL Ltd., Tokyo Japan). The morphological characteristics were then studied from SEM Micrographs.

2.11. X-ray diffractometry

Lotus stem starch samples were equilibrated above a saturated potassium sulphate solution (K_2SO_4) in a desiccator for two weeks. The hydrated starch powders were packed tightly in a circular aluminium cell and patterns were measured using a Philips X'PERT PRO XRD by exposing the samples to the X-ray beam from an X-ray generator running at 45 kV and 40 mA. The scanning regions of the diffraction angle 2Ø were 2–90°. Other operation conditions included: Step size (2Ø) 0.05, divergence slit size 0.4354, receiving slit width 0.1. Crystallinity of the starches was quantitatively estimated following the method of Nara et al., 1983 by using a software package (Orion – version 6.0 Microcal Inc., Northampton, MA, USA). A line connecting peak baselines was computer-plotted on the diffractogram. The area above the smooth curve was considered as the crystalline portion and the lower area between the smooth curve and a linear baseline was taken as the amorphous portion. The ratio of the upper area to the total diffraction area was calculated as the crystallinity. The moisture content of the samples was determined before and after scanning using moisture analyser (Model MA 100, Sartorius Germany).

2.12. Statistical analysis

Mean values, standard deviation, and analysis of variance (ANOVA) were computed using a commercial statistical package SPSS 10.1 (USA). These data were then compared using Duncan's multiple range tests at 5% significance level.

3. Results and discussion

3.1. Moisture content and apparent amylose content

The moisture content of the starch does not show any significant difference with the increase in radiation dose (Table 1). The results are in agreement with those of Mohd Adzahan et al. (2009) who reported gamma ray irradiated starches had the least amount of moisture loss.

Apparent amylose content (AAC) showed a significant reduction when compared to their native starch. Decreasing trend was observed while increasing the irradiation dose (Table 1). It decreased from 28.3% to 23.07% for lotus starch at 20 kGy. It could be probably due to severe degradation of amylose fraction that reduces the iodine binding ability of amylose resulting in smaller values of apparent amylose content (Sokhey and Chinnaswamy, 1993). The results were also

Table 1 Moisture, Amylose, Carboxyl content and pH of γ-irradiated lotus starch ($n = 5$).

Dose kGy	Moisture content%	AAC%	Carboxyl content%	pH
0	$12.5^{a} \pm 0.5$	$28.3^{a} \pm 0.5$	0.00^{a}	$4.25^{a} \pm 0.01$
5	$12.2^{a} \pm 0.2$	$27.13^{b} \pm 0.3$	$0.11^{b} \pm 0.02$	$4.00^{b} \pm 0.03$
10	$12.0^{a} \pm 0.1$	$25.5^{c} \pm 0.2$	$0.17^{c} \pm 0.04$	$3.80^{c} \pm 0.02$
20	$11.9^{a} \pm 0.4$	$23.07^{d} \pm 0.4$	$0.20^{d} \pm 0.01$	$3.45^{d} \pm 0.05$

Means followed by a different superscript letter in a column are significantly different ($p \leqslant 0.05$).

Table 2 Functional properties of γ-irradiated lotus starches ($n = 5$).

Dose kGy	Swelling power* (g/g)	AML*%	Water absorption capacity (g/g)
0	$3.0^{a} \pm 0.2$	$13.0^{a} \pm 0.8$	$4.00^{a} \pm 0.4$
5	$2.70^{b} \pm 0.5$	$17.15^{b} \pm 0.6$	$4.32^{b} \pm 0.2$
10	$2.47^{c} \pm 0.1$	$20.2^{c} \pm 0.4$	$5. 07^{c} \pm 0.3$
20	$2.02^{d} \pm 0.3$	$23.7^{d} \pm 0.7$	$5.33^{d} \pm 0.1$

Means followed by a different superscript letter in a column are significantly different ($p \leqslant 0.05$).
* Swelling power and Amylose leaching were carried out at 60 °C temp.

in agreement with those reported by Yu and Wang (2007), Chung and Liu (2010). Yu and Wang (2007) postulated that the decrease of apparent amylose content originated from the breakage or cleavage of partly branched long chains in amylopectin during irradiation. The apparent amylose content (AAC) of the native starch granules varies with the botanical origin, climatic conditions, and soil type (Morrison et al., 1984; Gani et al., 2010).

3.2. Carboxyl content and pH

The carboxyl content increased as irradiation dose was increased leading to a decrease in pH (Table 1). A substantial increase in carboxyl content was observed at 20 kGy. Gani et al. (2012) reported that the acidity of starch increased with increasing irradiation dose. Increased carboxyl content of the irradiated starch could be due to the breakdown of starch molecules by the action of free radicals, inducing the formation of carboxyl groups. Similarly, Chung and Liu (2010) reported that the carboxyl content of corn starch increased with increasing irradiation dose. The radiation degradation of starch is initiated by the generation and transformation of free radicals and follows the low-molecular products with the number of carboxylic acids and aldehydes. Ghali et al. (1979) reported that formic, acetic, pyruvic and glucuronic acids were formed during irradiation of starch. Therefore, the main degradation products formed during irradiation of native starch were carboxylic acids, which resulted in an increase in carboxyl content and a decrease in the pH value of all starch samples.

3.3. Swelling power and amylose leaching (AML)

Irradiation, at all the doses, caused significant reduction in the swelling index of lotus stem starch (Table 2). Swelling index decreased as the irradiation dose increased in all four starch samples. Swelling results from the ability of starch to trap and retain water within its structure (Whistler and Daniel, 1985). This capability may be diminished markedly once starch degradation occurs with irradiation. Since amylopectin fraction is primarily responsible for swelling (Tester and Morrison, 1990) and therefore a decrease in the swelling index may be related to a high reduction in amylopectin with irradiation. Kerf et al., 2001 reported a significant reduction in the amylopectin fraction of various starches with irradiation. The decrease in the swelling power could be beneficial to improve the textural quality upon cooking as the bursting of starch could be prevented.

Amylose leaching showed an increase with increasing radiation dose (Table 2). The increase in Amylose Leaching by gamma irradiation could be related to the production of low molecular weight fractions and degradation of starch structures (Chung et al., 2009; Chung and Liu, 2010). The results are also in agreement with those found by Mohd Adzahan et al. (2009) they reported leaching of amylose for sago and tapioca increased with increasing exposure to radiation.

3.4. Water absorption capacity

The results of water binding capacity of native as well as irradiated lotus starch are provided in Table 2. The results are in accordance with those of our previous work on kidney bean starches in which increase in water absorption capacity was observed by increasing the radiation dose from 5 to 15 kGy (Gani et al., 2012).The increase in WAC with irradiation may in part be due to irradiation-induced damage or degradation of lotus stem starch to simpler molecules such as dextrins and sugars that have higher affinity for water than starch. Other workers (Wu et al., 2002) have also reported depolymerisation of various starches following irradiation application.

3.5. Transmittance

Transmittance is the fraction of incident light at a specified wavelength that passes through a sample. The light transmittance of gelatinised starch pastes (1%) decreased sharply up to the 3rd day of storage and then remained almost constant (Table 3). However, the decrease in light transmittance was most pronounced during the 2nd day. The results are in accordance with those found in the case of Indian bean starches (Wani et al., 2010). Factors responsible for turbidity

Table 3 Transmittance (%) of γ-irradiated lotus starches ($n = 5$).

Dose kGy	Day-1	Day-2	Day-3	Day-4	Day-5
0	$1.00^{a} \pm 0.6$	$0.60^{k} \pm 0.8$	$0.35^{h} \pm 0.03$	$0.25^{m} \pm 0.01$	$0.24^{q} \pm 0.3$
5	$1.50^{b} \pm 0.4$	$1.09^{j} \pm 0.2$	$0.70^{g} \pm 0.05$	$0.41^{n} \pm 0.03$	$0.41^{r} \pm 0.2$
10	$1.75^{c} \pm 0.1$	$1.14^{l} \pm 0.7$	$0.82^{f} \pm 0.06$	$0.52^{p} \pm 0.05$	$0.51^{s} \pm 0.5$
20	$1.83^{d} \pm 0.8$	$1.12^{i} \pm 0.5$	$1.00^{e} \pm 0.08$	$0.74^{o} \pm 0.08$	$0.71^{t} \pm 0.7$

Means followed by a different superscript letter in a column and a row are significantly different ($p \leqslant 0.05$).

Table 4 Syneresis (%) of γ-irradiated lotus starches ($n = 5$).

Dose kGy	Day-1	Day-2	Day-3	Day-4	Day-5
0	$76.56^{a} \pm 0.5$	$77.31^{b} \pm 0.3$	$79.4^{c} \pm 0.12$	$79.26^{d} \pm 0.05$	$81.9^{e} \pm 0.04$
5	$72.32^{f} \pm 0.4$	$72.46^{g} \pm 0.6$	$70.96^{h} \pm 0.15$	$74.14^{i} \pm 0.01$	$76.51^{j} \pm 0.02$
10	$70.64^{k} \pm 0.1$	$71.78^{l} \pm 0.5$	$70.11^{m} \pm 0.2$	$72.84^{n} \pm 0.07$	$72.61^{o} \pm 0.06$
20	$65.29^{p} \pm 0.7$	$68.56^{q} \pm 0.4$	$68.17^{r} \pm 0.17$	$67.81^{s} \pm 0.03$	$69.37^{t} \pm 0.08$

Means followed by a different superscript letter in a column and a row are significantly different ($p \leqslant 0.05$).

Table 5 Pasting properties of γ-irradiated lotus starches.

Dose kGy	Peak viscosity (cP)	Hold Viscosity (cP)	Final Viscosity (cP)	Breakdown viscosity (cP)	Setback viscosity (cP)	Crystallinity (%)
0	$2718^{a} \pm 8.0$	$2290^{h} \pm 13.0$	$3393^{q} \pm 16.0$	$1103^{d} \pm 15.0$	$428^{d} \pm 14.0$	30.0 ± 0.5
5	$1569^{b} \pm 11.0$	$1029^{g} \pm 10.0$	$1130^{p} \pm 12.0$	$681^{e} \pm 7.0$	$325^{c} \pm 8.0$	29.4 ± 0.2
10	$920^{c} \pm 12.0$	$410^{f} \pm 16.0$	$525^{b} \pm 6.0$	$250^{c} \pm 17.0$	$320^{b} \pm 15.0$	28.8 ± 0.9
20	$350^{d} \pm 9.0$	$225^{e} \pm 18.0$	$270^{a} \pm 14.0$	$140^{f} \pm 10.0$	$210^{a} \pm 10.0$	28.3 ± 0.7

Means followed by a different superscript letter in a column are significantly different ($p \leqslant 0.05$).

development in starches during storage have been previously identified by many researchers (Craig et al., 1989) and include aggregates made of leached amylose, amylose and amylopectin chain lengths, intra or intermolecular bonding, granule swelling and granule remnants. The decrease reorganisation forms aggregates that reduce light transmittance of starch pastes (Tetchi et al., 2007). High amylose starches re-associate more readily than amylopectin starches thereby resulting in more opacity (Bultosa et al., 2002). Transmittance was found to increase with the increase in irradiation dose for all the samples; this may be due to the disintegration of starch particles on exposure to gamma-irradiation resulting in a clear solution.

3.6. Syneresis

Steady decrease in syneresis (%) was observed with increasing irradiation dose in lotus stem starches (Table 4). The reduction in syneresis may in part be attributed to decreased apparent amylose content at higher irradiation doses (Srichuwong et al., 2011). Decrease in apparent amylose content after irradiation treatment has been reported by Chung and Liu (2010), Yu and Wang (2007). It could partly be related to an amylopectin chain ratio which has higher water holding capacity, highly branched structure & shorter chains would retrograde in a slower rate (Biliaderis, 2009).

3.7. Pasting properties

Pasting properties (Peak, Breakdown, Holding, Final and Setback Viscosities) decreased considerably with increasing irradiation dose (Table 5). Peak viscosity (cP) was recorded in the range of 920.0 and 350.0 at 10 kGy & 20 kGy respectively. It is mainly related to the swelling of starch granules (Vandeputte et al., 2003). Substantial reduction in the swelling index in the irradiated starch due to its degradation upon its irradiation could be responsible for lowering of peak viscosity with increasing dose (Yu and Wang, 2007; Chung and Liu, 2010). The variation in the swelling index may account for the difference in peak viscosity among lotus stem starches.

The Setback & Final viscosities are largely due to the reordering or polymerisation of leached amylose & long linear amylopectin depolymerisation (degradation) of these molecules (Pimpa et al., 2007) led to a significant decrease in the setback & final viscosities. Similar results have been reported by Abu et al., 2006; Chung and Liu (2010). The difference in these viscosities among the starches may be assigned to their difference in the extent of polymerisation of leached amylose & amylopectin molecules. Breakdown results from the rupture of swelling granules. A decreased trend in breakdown was observed as the irradiation dose increased. The breakdown viscosity (cP) value was recorded as 140 at 20 kGy which could be ascribed to breakage of starch granules. The results were in agreement with those reported by Abu et al. (2006), Yu and Wang (2007).

3.8. Morphological properties and X-ray diffraction patterns

Granule size and size distribution of starch are unique properties of starch that have an influence on the functionality of the starches. Micrographs taken from scanning electron of lotus

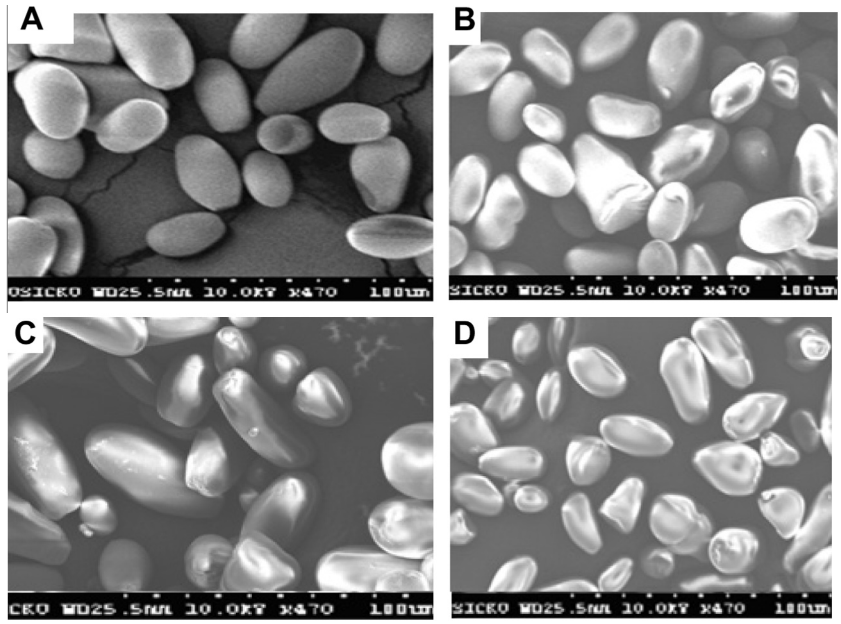

Figure 1 lotus stem starch A-0 kGy, B-5 kGy, C-10 kGy, D-20 kGy.

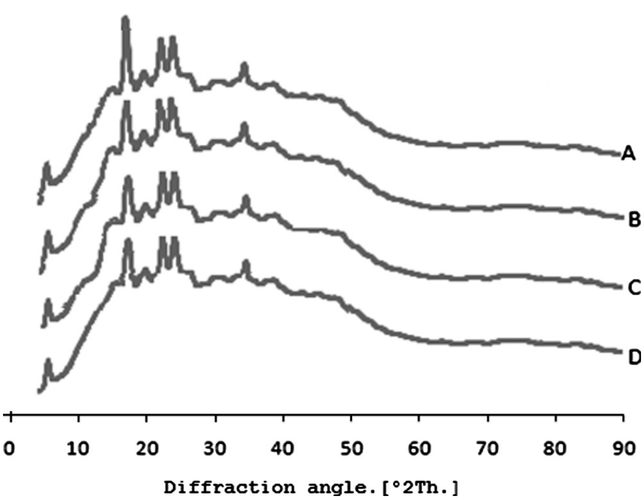

Figure 2 Lotus stem starch X-ray diffraction pattern A-0 kGy, B-5 kGy, C-10 kGy, D-20 kGy.

starches are presented in Fig. 1. All the lotus starch samples showed small rounded and typical oval-shaped granules with a smooth surface, but some have dents or hollows at one end. The difference in granule morphology may be attributed to the biological origin, biochemistry of the amyloplast and physiology of the plant (Sandhu et al., 2004).

All starch samples displayed B-type pattern of lotus stem starch (Fig. 2). The irradiated starch showed no significant change in diffraction pattern when compared to non-irradiated starch. However, the relative crystallinity decreased with increasing radiation dose (Table 5). Similar findings have been reported by Gani et al. (2012) and Ciesla et al. (1991) who observed a decrease in relative crystallinity of irradiated Kidney bean and potato starch at 5–20 kGy respectively. They claimed that the decrease in relative crystallinity was due to destruction of long ordered structure of crystalline and amorphous regions in starch granules. Chung and Liu (2010) also observed a decrease in the relative crystallinity of potato and bean starches after gamma-irradiation at 50 kGy.

4. Conclusion

Gamma-irradiation induced the degradation of amylose and amylopectin and consequently altered the physicochemical properties, including an increase in carboxyl content, solubility, transmittance and water absorption capacity, and a decrease in swelling index, apparent amylose content and syneresis. The scanning electron micrographs showed size reduction and cracking of starch granules in irradiated starch. X-ray diffraction pattern remained the same upon irradiation but a slight decrease in peak intensity was observed. The pasting properties decreased drastically with increasing irradiation dose. The decrease in the swelling index could be beneficial to improve the texture upon cooking. It will be suitable to use in frozen food products in the wake of its reduction in syneresis.

Acknowledgements

Authors are thankful to Department of Biotechnology, Govt. of India; Department of Physics IIT, Delhi and Baba Atomic Research Centre, Srinagar.

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